



Nature Suggests a Promising Strategy For Lightweight Composites

Scientific American names Tomsia

one of the year's top 50 technology leaders for the discovery

A Berkeley Lab team led by Antoni Tomsia has harnessed the mechanism by which seawater freezes to develop novel light-weight mineralized materials with unique mechanical properties. They have fabricated new porous scaffold-like materials that are four times stronger than similar materials used today. Although still in the investigational stages, variations of this technology could be used in a myriad of applications in which strength and lightness are imperative, such as airplane parts and computer hardware, and dental implants.

Structure of Oyster Shell nacre mimicked in novel freeze-cast material

Emerging technologies in fields as diverse as energy generation, structural applications, and biomedicine require new materials with unique combinations of properties able to deliver complex functionalities. For example, an optimum scaffold for bone tissue engineering should possess an interconnected pore network with tailored surface chemistry for cell growth and penetration and the transport of nutrients and metabolic waste. It should degrade at a controlled rate, release drugs and/or bone growth factors, and its mechanical properties should match those of natural bone. At the same time, new efficient technologies, in the energy or automotive industries demand composites that combine lightweight, strength and toughness in a way that cannot be achieved using conventional processing. The development of these materials calls for new design paradigms based on a thorough understanding of the relationship between the materials architecture and its properties.

Nature has addressed these challenges over millions of years of evolution. An example is the intricate structure of nacre, the finely layered substance in the shells of some mollusks such as oysters and abalone. Scientists have long sought to duplicate nacre's unique combination of strength and lightness in ceramic materials, but its architecture varies at several length scales, from micrometers to nanometers. Replicating all of these scales — each of which contributes to the overall performance — in a synthetic substance has proved to be extremely difficult.

The key insight into replicating this level of structural organization and complexity involved mimicking the mechanism of sea ice formation.

When seawater freezes, crystals of pure ice form layers while expelled impurities such as salt and microorganisms migrate into channels between the crystals. The result is a layered structure that roughly resembles nacre's wafer-like construction. The Berkeley Lab team adapted this mechanism and froze a watery suspension of ceramic powders. Like the impurities in sea ice, the ceramic concentrated in the space between the ice crystals. After the ice was removed via sublimation, a porous ceramic scaffolding that exhibited striking similarities to nacre's multi-layered structure remained. [The thickness of the ceramic layers could be controlled from 1 to 100 μm through the manipulation of the speed of the ice front.] Like nacre, the surfaces of the layers are rough, helping them lock in place. In addition, the toughening interaction in nacre of the inorganic layers with the organic film of protein between them was mimicked by filling the porous ceramic scaffolds with a second organic (polymer) or inorganic (metal) phase.

In the future, the Berkeley Lab scientists hope to use this material in the development of new lightweight composites or scaffolds to foster bone tissue regeneration. The later will be achieved by filling the space between the scaffolding's layers with a biodegradable organic polymer containing antibiotics and compounds that stimulate bone growth. Then, the composite can be placed in the body where new bone needs to grow. Over time, the polymer will degrade, the scaffolding become more porous, and the growth factor will be activated, prompting bone cells to invade the newly created pores and grow new bone.*

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